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Wind farm efficiency assessed by WRF with a statistical-dynamical approach

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Installed wind power has increased significantly in the last decade and is expected to increase further. With increasing installed wind power it becomes important to investigate if wind farms continue to be efficient power generators also when covering larger areas.

We use the Weather Research and Forecast model with a wind farm parametrisation to simulate the flow field in hypothetical on- and offshore wind farms that range from $25\,\mathrm{km}^2$ to $1.1\cdot10^5\,\mathrm{km}^2$. The simulations use "idealised" forcing conditions to drive the WRF model. Regional wind climates are then obtained from a series of simulations that range between the turbine cut-in and cut-out wind speed. We use the wind farm efficiency, i.e. ratio between the power production with and without wake effects, and the Annual Energy Production to assess the wind farm feasibility in the U.S. Great Plains (onshore), North Sea (offshore), and strait of Magellan (offshore).

We will show why in onshore regions with moderate wind conditions there is a small gap in efficiency between small and very large wind farms. Therefore, despite the relatively weak winds, very large wind farms remain relatively efficient power generators. Then we discuss why very large wind farms in the North Sea – although exposed to better free-stream wind conditions than in the Great Plains – exhibit relatively larger wake loses than over land. Here clusters of smaller wind farms, with are broader turbine spacing than conventionally used, are the better option. For the North Sea, we show examples of hypothetical wind farm clusters. Finally, in offshore regions with very strong winds small wind farms become extremely efficient and produce considerably more than in the North Sea. Here also very large wind farms are significantly more efficient compared to those in the North Sea.